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Evaluating the Growth Potential of Aspen Lands in Northern Minnesota

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Cover picture. -- A 45-year-old aspen stand on a good site in the Chippewa National Forest. The stand averages 315 trees per acre and contains 115 square feet of basal area.

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Evaluating the Growth Potential of Aspen Lands in Northern Minnesota

by R. O. Strothmann[1/]

Introduction

As forest management practices are intensified, foresters find an increasing need for information enabling them to recognize land productivity. They wish to know before they spend money on a tract of land how well it will grow the type of forest products in which they are interested. They want a practical way for determining site quality, even though the land may be deforested or have only a young stand on it at the time of their appraisal.

With the increase in the commercial importance of quaking aspen (*Populus tremuloides* Michx.) in the Lake States during the past several decades, there has been a growing interest in the development of a site productivity rating scheme for this species. Much work has already been done on soil-site relationships for aspen. Most of this work, however, has consisted of rather detailed examinations of some particular soil or topographic characteristic as it affects site quality. Taken by themselves, many of these studies were of limited value to the practicing forester. Often they dealt with the influence of a single factor, or else they required the use of complex laboratory techniques with which the practicing forester may be unfamiliar.

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The present study, started in 1953, was aimed at developing a workable site rating scheme that required no elaborate soil testing equipment nor any specialized soils knowledge on the part of the forester using the scheme. The intention was not to uncover new fundamental knowledge of aspen sites, but rather to apply existing knowledge.

In the early phases of the study a comprehensive literature review was made. This was published in 1955.[2/] Since then a site rating scheme has been developed and is presented in this report, along with a discussion of its use, some of its weaknesses, and suggestions for additional research.

Description of Area

The study was confined generally to the northeast half of Minnesota which comprises the main body of the commercial range of aspen in the State. The counties included in the study were Cook, Lake, St. Louis, Koochiching, Itasca, Lake of the Woods, Beltrami, Roseau, Clearwater, Mahnomen, Becker, Hubbard, Wadena, Cass, Crow Wing, Morrison, Aitkin, Mille Lacs, Kanabec, Pine, and Carlton (fig. 1). The only portion of this area specifically excluded was the rock outcrop region of northern Cook, Lake, and St. Louis counties, a unique area that presents the special problem of shallow soils.

Surface Geology

The surface geology of northern Minnesota has an important bearing on aspen site quality because topography and soil parent materials are determined by landforms. Almost all of the landforms in this region are the result of either glacial deposition or glacial erosion. At least four surface drifts are present in the aspen-producing areas. Each is the result of deposition by ice lobes that traversed different source regions with varying bedrock types.

2/ Heinselman, M. L., and Zasada, Z. A. A review of literature relating to quaking aspen sites. U.S. Forest Serv., Lake States Forest Expt. Sta., Sta. Paper 32, 61 pp. 1955. (Processed.)

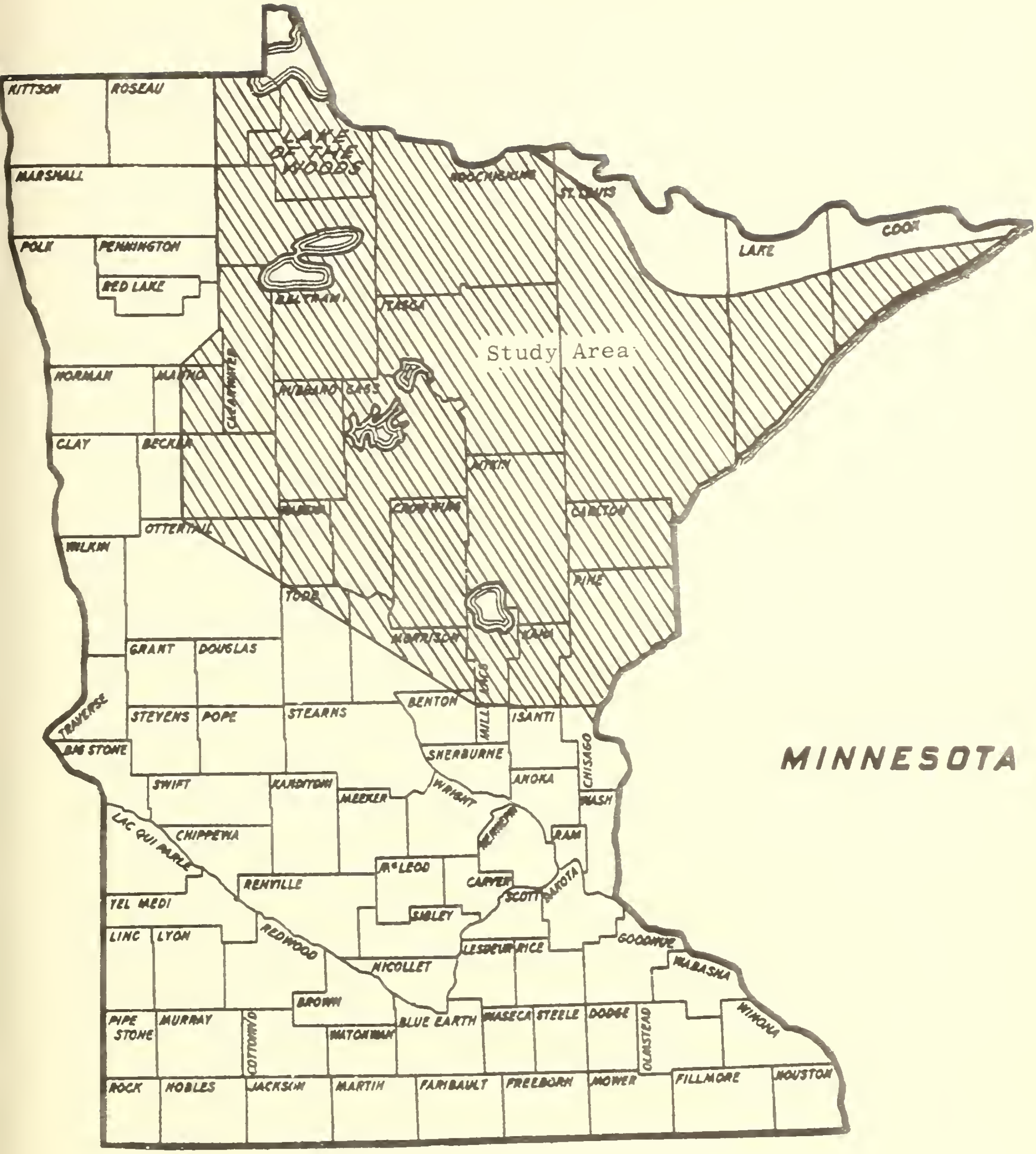

Figure 1.--Area included in the site study.

The gray drift of northwestern Minnesota tends to be fine-textured and limy. This drift owes its color and lime content to the limestone and shales of the Manitoba source region. Gray drift extends eastward into western St. Louis county, and is common in Koochiching, Itasca, Cass, northern Aitkin, Wadena, and Todd counties. It is also found in all counties northwest of these.

A red sandy drift occurs at the surface over much of Carlton, Aitkin, Pine, Kanabec, Mille Lacs, Crow Wing, southern Cass, and southern St. Louis counties. This drift is usually coarse-textured, rocky, and lime-deficient. Its source was the acidic rocks of the Laurentian Shield and the red sandstones of the Lake Superior region.

Brown sandy drift is common in Lake, Cook, and northeastern St. Louis counties, and in parts of Mille Lacs, Crow Wing, and Morrison counties. This drift was also derived from the Laurentian Shield, but the ice did not traverse the red clastics of the Lake Superior basin.

A red clayey drift is found at the surface in parts of Carlton, Aitkin, southern St. Louis, northern Pine, northern Mille Lacs, and eastern Crow Wing counties. This drift is believed to be the result of a reworking of Lake Superior clays. It contains some lime, and usually occurs as a relatively thin and discontinuous veneer over red sandy, brown sandy, or gray drift.

In general, the tills of the gray drift region are fine sandy loams to clay loams and are not as stony as the others. Tills in the red sandy and brown sandy drift regions tend to be sandy loams or loamy sands and are quite rocky. Many of the till soils occur in morainic areas (such as the Marcell area in Itasca county) where topography is rough, and stone content extremely variable.

Several extensive areas of outwash occur in the region such as in the Cass Lake-Bena vicinity of Cass county, and in Wadena, Hubbard, and Crow Wing counties. Outwash soils are mostly sorted, stone-free sands and gravels. Smaller pockets of outwash are common throughout the aspen region.

At least four large glacial lake beds are present: Lake Agassiz, Lake Aitkin, Lake Upham (Floodwood area), and Lake Duluth. Where these beds are not covered with muskeg, the surface soils are mostly clays and silts, with occasional patches of beach sands.

Topography

The topography of the aspen region is a product of the landforms in each specific area. The Lake Agassiz, Lake Aitkin, and Lake Upham sections are nearly level, as are many of the outwash plains. There are also some gently rolling till plains. Moraines vary from gently to sharply rolling, with local relief of 100 to 300 feet not uncommon. Several well-defined moraine systems are present such as the Altamont-Gary and Bemis moraine complex in the west, the Mille Lacs moraine and St. Croix moraine in the south, and the Highland moraine in the Lake Superior area.

Climate

A distinct climatic gradient exists within Minnesota's aspen forest area. The northwestern part of the State has colder winter temperatures and warmer summer temperatures than the northeastern part. This is due largely to the influence of Lake Superior in the northeast which moderates the temperature extremes. Also, average temperatures increase from 5 to 10° F. in moving from the northwest to the central part of the State.

Precipitation decreases from east to west with a maximum for the aspen region of 30 inches annually in Cook county, and a minimum of 20 inches in Roseau county. Humidity also decreases from east to west. The combined effect of these gradients in temperature, precipitation, and humidity is to produce a growing season climate which is distinctly warmer and drier in the south and west than in the northeast.

Local variations in climate are small because of the lack of topographic relief, except for the area immediately adjacent to Lake Superior. Here the effects of the lake itself, and the 1200-foot relief of the north shore range, combine to produce a definite local climate near the lake that is more humid and less continental than further inland.

Soils

The complex patterns of parent materials, topography, climate, and natural vegetation have produced a variety of soils. A detailed description of soil types is beyond the scope of this study, and in fact no such information is available for much of the forested, nonagricultural areas in the State. It should, however, be emphasized that the aspen soils of Minnesota are highly variable, both as to physical and chemical properties. This variability allowed the testing of soil-site factors over a wide range of conditions, but also presented the problem of varied soil conditions on relatively small areas.

Study Methods

The study involved the taking of 257 plots, 22 of which were exploratory, during the field seasons of 1954, 1955, and 1956. To insure good geographic coverage of the area, the plots were allocated among the counties previously mentioned on the basis of county size and the relative importance of the aspen type in the county. Thus, St. Louis county was assigned 30 plots and Mahnomen only 2.

The study area was subdivided into four major quadrants with Grand Rapids at the center. Approximately equal numbers of plots were taken in each quadrant to assure that the full climatic range of the area would be adequately covered.

The factors which were selected for testing fall into three major groupings: soil characteristics, topographic features, and fire history of the stand. The specific factors chosen were those which previous research had found useful in predicting site index of aspen. The soil factors included the percent of silt-plus-clay and percent of stoniness of the upper 36 inches of soil, the silt-plus-clay content of the subsoil, the pH (acidity or alkalinity) of the subsoil, and the depth to hardpan and to mottling if these were present. Subsoil samples were taken between 36 and 72 inches, and subsoil pH was the pH at the bottom of the test hole (usually 72 inches).

In keeping with the intent of developing a method which could be used by practicing foresters, these soil features were measured with field equipment. For making the silt-plus-clay determinations, the Cenco-Wilde soil colloid tester was used. Determinations of pH were made with a Hellige-Truog soil reaction kit. The stoniness of the soil was determined by passing a representative sample through several sieves and expressing the stony portion (particles 2 mm. and larger) as a percentage, by weight, of the total soil sample. The term "stoniness" as used here includes particles of gravel size as well as pebbles and boulders without regard to their respective proportions in the total stone content.

Since most foresters are not soils specialists, the soil on each plot was sampled by fixed depths rather than by profile horizons. A soil pit was dug on each plot, generally to a depth of about 3 feet. A posthole auger was used in the bottom of the pit to go down an additional 3 feet to determine the depth to water if it was within 72 inches of the soil surface.

Topographic features recorded were the percent of slope (measured with an Abney level), the aspect (read from a hand compass), and the position on the slope. Plots with slopes of less than 5 percent were considered to be essentially flat, having no slope, aspect, or position.

The fire history was classified into one of three categories: (1) favorable if there had been no fires since stand establishment, and only one moderate to heavy burn prior to establishment; (2) somewhat damaging if there had been no fires since establishment, but heavy or repeat burns prior to establishment; (3) very damaging if the area had been burned both before and after stand establishment. Areas that show no evidence of ever having burned but are now in aspen are not common; these were placed in category 1 when encountered.

The fire history class for each plot was determined largely by circumstantial evidence, and admittedly the evidence might be interpreted differently by different observers. Essentially, the guidelines were as follows: A "favorable" fire history was indicated if species other than aspen were present and if these were older than the aspen in the stand. By this was meant numerous trees of other species--not just one or two old pine remnants. A "somewhat damaging" fire history was indicated if the stand was essentially even-aged, possibly containing species other than aspen, but not shade-tolerant trees of older age classes (unless they were badly fire-scarred). A "very damaging" fire history was indicated if two or more age classes of aspen were present, with fire scars apparent on the older trees; other species would seldom be present except as reproduction.

In addition to the stand characteristics described above, other information such as the presence and amount of charred material in the duff and humus and the presence and severity of fire scars on stumps, was taken into account in deciding which fire history class was most appropriate for each plot.

A number of conditions were considered in choosing the actual plot locations. Basic requirements were that the stands be at least 30 years of age, ungrazed, and reasonably well stocked, and that quaking aspen comprise at least 50 percent of either the volume or number of stems on the plot. Bigtooth aspen (*Populus grandidentata* Michx.) and balsam poplar (*P. balsamifera* L.) occurred on some of the plots, but only quaking aspen were used as sample trees. In addition, the stand must not have undergone any periods of suppression, nor should its development have been affected by unnatural drainage conditions such as are caused by road fills and ditches.

It was not feasible to rule out stands which had been defoliated, since virtually every major aspen area in Minnesota has been defoliated at some time by the forest tent caterpillar. To eliminate such stands would have meant a drastic reduction in the population of aspen eligible for the study.

The Site Rating Scheme

The study brought out the wide range in aspen site quality in northern Minnesota. The best plot encountered had a site index of 98 (fig. 2), and the poorest a site index of 43 (fig. 3). These are probably close to the extremes which exist in this area.

Developing a good scheme for predicting site quality, however, proved to be more difficult than recognizing that site quality differences exist. Before beginning the fieldwork a tentative rating scheme had been devised on the basis of the literature findings. This was intended mainly as a starting point or framework from which the final predicting chart could be developed. There is little to be gained by presenting the details of this original scheme, or of the several modifications leading to its final form. Only the final version will be discussed here.

The scheme is presented in two parts, the first of which (tables 1 and 2) defines what constitutes favorable, average, or unfavorable topography, and also what characteristics make a soil excellent, good, fair, or poor. The second part (table 3) shows the site index values for aspen which combinations of these topographic and soil classes can be expected to produce in northern Minnesota.

The decision to divide the soil rating into four classes and the topography rating into three classes was an arbitrary one. The purpose was to find a happy medium between too much lumping together of differences on the one hand, and unwarranted refinement on the other.

Figure 2.--The best site encountered in the study. The dominant trees averaged 82 feet tall at 37 years of age which represents a site index of 98 at age 50.

Figure 3.--The poorest site encountered in the study. The dominant trees averaged 42 feet tall at 47 years of age which represents a site index of 43 at age 50.

Table 1.--Rating of topographic factors[1/]

Slope (Percent)	Aspect	Topographic position	Topography rating
5-20	S and SW	Lower slope	Average
		Upper and middle slope	Unfavorable
	W,NW,N,NE,E,SE	Lower slope	Favorable
		Upper and middle slope	Average
21 or more	S and SW	Lower slope	Unfavorable
		Upper and middle slope	Unfavorable
	W,NW,N,NE,E,SE	Lower slope	Average
		Upper and middle slope	Unfavorable
---	---	Depression	Average
---	---	Ridgetop	Unfavorable

1/ Land with less than 5 percent slope, other than depressions, or ridgetops, was considered as flat and hence without slope, aspect, or position.

Table 2.--Rating of soil factors

Percent of stoniness in upper 36 inches of soil	Percent silt + clay of upper 36 inches of soil, and water table relationships	pH of subsoil	Soil rating
0-30	0-9 (w.t. below 60 inches)	Any	Poor
	0-9 (w.t. 0-60 inches)	Any	Fair
	10-20	Any	Fair
	21-30	Any	Good
	31+ (w.t. 0-24 inches)	Any	Good
	31+ (w.t. below 24 inches)	6.9 or less	Good
	31+ (w.t. below 24 inches)	7.0 or more	Excellent
31 or more	0-9 (w.t. below 60 inches)	Any	Poor
	0-9 (w.t. 0-60 inches)	Any	Fair
	10-20	Any	Fair
	21-30	Any	Fair
	31+ (regardless of w.t.)	Any	Good

Table 3.--Aspen site prediction scheme combining soil and topography ratings (based on 235 plots)

Topography rating 1/	Soil rating 2/	Site index: Average	Site index: Highest	Site index: Lowest	Number of plots
On sloping land:					
Favorable	Excellent	86	90	83	2
	Good	78	97	59	13
	Fair	74	74	74	1
	Poor	(3/)	(3/)	(3/)	0
Average	Excellent	76	85	60	7
	Good	69	77	57	12
	Fair	66	87	52	10
	Poor	(3/)	(3/)	(3/)	0
Unfavorable	Excellent	72	79	68	3
	Good	68	76	61	10
	Fair	59	72	50	4
	Poor	44	45	43	2
On flat land: 4/					
	Excellent	74	90	57	63
	Good	70	91	57	46
	Fair	66	82	53	52
	Poor	57	70	50	10

1/ See table 1 for descriptions of topography ratings.
2/ See table 2 for descriptions of soil ratings.
3/ No data were obtained in these categories.
4/ Having slope of less than 5 percent.

The soil and topography ratings assigned to certain conditions in tables 1 and 2 are based on the influence of these conditions as reported in the literature, and subsequently modified by the findings of the present study for Minnesota conditions. For analysis the plots were stratified in numerous ways, allowing certain conditions to vary while keeping others constant. This revealed the underlying pattern of influence for each factor, and the conditions under which it was of greatest importance.

The topography ratings in table 1 show the composite effect of slope, aspect, and position. Plot findings were in agreement with the reported results of past research work, showing, for example, that the poorest sites were those occurring on steep upper or middle slopes with south or southwest aspects. This comes as no surprise, but it was a necessary step in working out the quantitative effect which specific combinations of these factors have on aspen site index.

As has been found true for many other species, soil texture and soil moisture (as indicated by water table relationships) are of major importance in determining site quality. The influence of soil texture is felt most at the low end of the silt-plus-clay range where small changes in silt-plus-clay content are associated with fairly large changes in aspen site index. As silt-plus-clay content increases above 30 percent, improvement in site quality is much less pronounced, tending to level off at the higher silt-plus-clay values.

Depth to the water table, as would be expected, is of greatest importance on the sandy soils. On very sandy soils (having a silt-plus-clay content of less than 10 percent), a water table within 60 inches of the soil surface improved the site index about 10 feet over soils of similar texture with water tables below 60 inches. For clayey soils, on the other hand, a shallow water table can be detrimental, especially if it occurs within 24 inches of the soil surface.

An increase in subsoil pH between values of 5.5 and 8.2 was correlated with an improvement in aspen site quality. This trend was consistent but not strong enough to alter, in most cases, the soil rating class as determined by soil texture and water table depth (table 2). Only on the finer-textured soils with deeper water tables was a separate category required on the basis of subsoil pH.

The effect of stoniness in the upper 36 inches of soil is to cause a general decrease in site quality as stoniness increases. However, as in the case of subsoil pH, variations in stoniness did not have a major impact on site quality. For this reason only two stoniness classes are incorporated in the rating of soil factors (table 2).

Tables 1, 2, and 3 are to be used together. Tables 1 and 2 classify, according to similarity of their overall effect, specific combinations of soil factors and of topographic factors. The end results are four soil rating classes, and three topographic rating classes. Table 3 then attempts to bring together by means of these rating classes, the influence of soil and topography, and to show what site index values can be expected from their interaction. More will be said later about how to put the system into actual use.

The separate listing of flatland in table 3 perhaps warrants some explanation. Since flatland by definition has no (or very little) slope, aspect, or position, these factors do not exert any influence on upgrading or downgrading flatland sites. Hence, flatland site prediction is based entirely on soil and water table characteristics. In terms of aspen growth, flatland sites perform quite similarly to sloping land sites with an "average" topography rating.

The tentative rating scheme devised at the outset of the study incorporated fire history as a pontential variable affecting aspen site index. However, subsequent analysis showed that fire history, as classified in this study, exerted no important influence on site quality. The plots with very damaging fire histories averaged only about 3 feet poorer in site index than comparable plots without severe fire histories. Even this small difference represents not only the effect of fire on deteriorating the site, but also its injurious effect on the growth of the present stand. Therefore the rating scheme presented here does not use fire history as a factor in predicting aspen site index.

Examination of the site prediction table (table 3) reveals an orderly pattern of values with respect to both soil ratings and topographic ratings. It shows a difference of 42 feet between the average site indexes of the best and poorest site classes. The maximum site difference between individual plots was somewhat larger (55 feet), but these plots represent extreme conditions. On the whole, the table covers pretty well the normal range of aspen sites encountered in northern Minnesota.

Some Limitations of the Method

While the table has value as a general guide for determining site quality for aspen based on soil and topographic features, its limitations must also be recognized. Its two most serious weaknesses are large internal variations within some of the rating classes, and the small number of plots which form the basis for some of the predicted site index values.

The large range of values within some classes is attributed to two things: (1) the existence of some important factors influencing site quality which were not tested in the study; and (2) the relative crudeness of the field techniques which were employed. The shortage of data in certain categories indicates that it would have been better to emphasize sampling by condition classes rather than by counties or other geographic considerations.

The type of approach used in allocating plots and in developing the prediction chart does not lend itself to conventional analysis of variance techniques because of problems of unequal variances and "missing" data. However, to aid the potential user in deciding how much confidence he should place in the predicted site values, the range for each category is given along with the number of samples upon which each average is based.

Among the factors not tested are such things as the soil nutrient level, special local environmental conditions, and genetic characteristics. The soil nutrient level, for example, depends on a number of things. Soil texture is a rough index of nutrient conditions, but other features are also involved. These include the type of soil parent material, its rate of weathering, and the nature of the soil organic matter. Two soils with the same percentage of silt-plus-clay may be quite different as to the supply of exchangeable bases and associated fertility factors.

Soil nutrient factors were investigated during the reconnaissance phase of the study, and the results were published in 1957.[3/] Good correlations were obtained between mean annual increment and exchangeable potassium, calcium, and magnesium in the A_0 horizon. Soil nutrient analyses, however, are complex and costly, and the aim of the present study was to see whether a workable site prediction scheme could be developed without recourse to such elaborate procedures.

Soil characteristics below a depth of 72 inches were not studied. Such depths are below the normal rooting zone of aspen, but could nevertheless have some influence on conditions in the upper soil and thus on the aspen. Impermeable layers below 72 inches could, for example, affect internal drainage and capillary movement of water in the upper soil zone.

3/ Voigt, G. K., Heinselman, M. L., and Zasada, Z. A. The effect of soil characteristics on the growth of quaking aspen in northern Minnesota. Soil Sci. Soc. Amer. Proc. 21: 649-652. 1957.

Local environmental conditions, such as topographic features either favoring or preventing the occurrence of damaging frosts, could make a site poorer or better than would otherwise be indicated. This would not necessarily be taken care of by the topographic rating class because such factors as the proximity of a large body of water can exert an independent influence. Also flatland that is lower than the surrounding area has a different localized climate than flatland which lies above the surrounding area.

Clonal variation, though not a site factor, may at times account for a large share of the difference in growth between stands on apparently similar sites. It is known that such variation exists in bigtooth aspen, and very likely it also exists in quaking aspen. An entire clone, consisting of several dozen trees, may be either genetically superior or inferior in growth characteristics in comparison with the surrounding stand or other stands on similar sites.

The crudeness of the field measurement techniques is certainly responsible for some of the lack of precision in the prediction scheme. The hydrometer-type field kit used for measuring the silt-plus-clay content of the soil is reasonably accurate for soils with less than about 40 percent silt-plus-clay. For soils with more than this amount (and many aspen soils have more) problems of dispersion of the fine particles arise. For clay soils especially, some clods strongly resist dispersion efforts. An additional chance for error is introduced by the need to estimate ocularly half of the normal sample when testing a fine-textured soil.

Regardless of the equipment used, it is felt now that sampling of the soil profile should have been done by a larger number of depth classes. Silt-plus-clay measurements should probably have been made on each foot of the upper 3 feet of soil. This would have given more recognition to the importance of any narrow clay layers, and would still have had the advantage of fixed-depth sampling requiring no great knowledge of soil profile development.

Depth to the water table is not a constant figure for a given site. It usually varies somewhat from spring to fall and from year to year. In conducting this study it was impractical if not impossible to measure the depth of the water table on 257 widely scattered plots during a single season. But the importance of water table depth as a factor in determining site quality could have been evaluated more precisely if all plots could have been examined during a single growing season.

The original aim of the study--to try to develop a useful site prediction chart for quaking aspen based on factors previously reported as influencing site quality, and on simplified field techniques--was only partially fulfilled. A site prediction scheme for aspen was developed, but it does not predict site index very precisely.

The hope of finding a simple, yet accurate measure of site productivity is universal. At present it seems too much to expect for an area as diverse as northern Minnesota. The complex pattern of landforms, glacial drifts, and soil types is apparently not adequately appraised by measuring a few of the soil and topographic characteristics with simple field equipment.

Application of the Rating Scheme

While the prediction scheme is not as good as was hoped for, it does have utility if its limitations are kept in mind. To use the scheme for site evaluation, measurements of four soil characteristics and three topographic characteristics must be made. This requires the following steps:

1. Measure the silt-plus-clay content of the upper 36 inches of soil with a Cenco-Wilde soil colloid tester. The detailed intructions for use are included with the kit. The soil sample should be well mixed and contain the various segments of this zone in proper proportion.

2. Determine the percent of stoniness in the upper 36 inches of soil. This is done by first weighing a representative sample of this soil, including stones. Then the sample is passed through several sieves, the smallest of which separates out all particles 2 mm. in diameter and larger. The stony portion (2 mm. and larger) is then weighed and expressed as a percentage of the original total weight. Actually this test often will not be necessary because the rating chart makes only one breakdown on stoniness which comes at 30 percent. With a little practice an investigator can usually tell without sieving whether a soil has more than, or less than, 30-percent stone content.

3. Determine by means of a soil auger or posthole digger whether the water table is within 60 inches of the soil surface, and if so, measure and record the depth. Water table, as used here

means the depth to actual free water standing in the hole.

4. Test the subsoil pH with a Hellige-Truog soil reaction kit. Detailed instructions are included with the kit. The test should be run on a soil sample taken from well down into the parent material, preferably at a depth of 5 to 6 feet. This pH test need only be run if the soil has a silt-plus-clay content of 31 percent or more, a water table below 24 inches, and a stone content of 30 percent or less.

5. Measure the slope of the land with an Abney hand level or other suitable instrument. If it is less than 5 percent, consider the site to be flat and skip steps 6 and 7.

6. Determine the aspect (N, NE, E, SE, S, SW, W, NW) with a hand compass.

7. Decide upon the appropriate topographic position (upper slope, middle slope, lower slope, ridgetop, or depression) and classify accordingly. Divide slope into thirds to decide between upper, middle, or lower slope positions.

After obtaining the information required above, refer to tables 1 and 2 to find the correct soil and topography ratings for the site under consideration. If the land is essentially flat, only the soil rating is needed.

Finally, using the appropriate soil and topography ratings, consult table 3 for the predicted site index value of the land in question.

Future Aspen Site Research Needs

Although much has already been done in the field of aspen site work, much more needs to be done before reliable predictions can be made for the great variety of conditions on which the species occurs. Past research has uncovered key relationships between specific site characteristics and site quality. Some of the important factors influencing site quality in specific localities have been identified and their quantitative influence established. These have served to fill in parts of the overall pattern, but large voids in the site picture still remain.

The present study indicated that more of the basic "building blocks" of knowledge are needed before we are ready to knit them together into a single scheme tailored for use over a large area. We still lack detailed fundamental knowledge of the influence of topography. Also, the relationship of water table depth to site quality needs further investigation. Even the relationship of soil properties to site quality (where most of the past work has been concentrated) needs amplification.

Future research can profitably be channeled into all of these fields. Topography, for example, requires more study to determine the influence of slope, aspect, and position on temperature, humidity, soil water movement and other factors which directly affect plant growth.

The role of soil moisture on site quality is unquestionably an important one. At present we really do not know how useful a single observation on water table depth may be. The depth varies as seasons change from wet to dry or vice versa. We generally assume that water table depth in the middle of the growing season is of greatest importance for tree growth. This is probably true, but to date we have little or no direct experimental evidence to substantiate this for quaking aspen. What is needed are some long-term studies in which the water level and soil moisture regime are observed on permanent plots over a period of years.

As for studies of the physical and chemical properties of soils, there should be no need to repeat basic work already done. However, even those who have worked most actively in this field will admit that we do not yet have all the answers. We need to learn more about the nutrient requirements of aspen and the factors governing nutrient availability. We also need to learn more about the significance of unusual soil profile characteristics such as narrow bands of clay in an otherwise sandy soil. We need to find out whether there are limiting soil factors which allow rapid early growth, but put a "ceiling" on development before the stand reaches maturity.

Several other facets of the site problem also need study. While fire history failed to show up as an important factor in the present investigation, it may actually have an appreciable effect on site quality if evaluated differently. Development of less subjective criteria for classifying fire history, perhaps by coupling specific physical evidence with records of known fires, may reveal that the severity and frequency of past fires do appreciably affect site quality.

Also, though not a site factor, more needs to be learned about the range of clonal variation possible for quaking aspen in a given region. Until this is better understood we cannot be sure how much of the difference in aspen growth on two areas is due solely to site differences.

Summary

A study was made aimed at developing a site prediction scheme for quaking aspen in northern Minnesota that would require only simple field techniques readily applicable by practicing foresters. The factors investigated were those reported in the literature as being important determinants of aspen site quality.

A scheme was developed, based on four soil factors and three topographic factors. The soil factors are the percent of silt-plus-clay in the upper 36 inches of soil, the percent of stoniness in this upper soil zone, the pH of the subsoil, and the depth to the water table (if within 60 inches of the soil surface). The topographic factors are the steepness of the slope, the position on the slope, and the slope direction or aspect.

The site prediction chart indicates a difference of 42 feet between the poorest (site index 44) and best (site index 86) classes, based on 235 plots scattered throughout the aspen producing region of northern Minnesota. A wide range of landforms, glacial drifts, and soil types were represented.

The prediction chart can serve as a useful general guide, but its limitations must be recognized. Its most serious weaknesses are the large variations in site index between plots within some of the categories, and the small sample size upon which some of the predicted values are based. Both the range of values and the size of the sample are given for each category in the chart.

The shortcomings of the prediction scheme are attributed mainly to the existence of some important factors which were not tested, and to the relative crudeness of the field techniques which were employed, particularly in measuring soil characteristics.

Although aspen is a fire species and most aspen stands in Minnesota owe their origin to fire, the severity of the fire history (as classified in this study) did not seem to affect site quality greatly.

Plots showing evidence of severe fire histories averaged only 3 feet poorer in site index than those whose fire histories were judged as much less severe.

It is concluded that more of the basic "building blocks" of knowledge in the total site picture are needed before they can be drawn together into a comprehensive scheme. Also it may be too much to expect that any simplified scheme will work well in an area as complex geologically and edaphically as northern Minnesota.

Some suggestions are offered as to the direction which future research on aspen site problems should take. More work on nutrient requirements and nutrient availability, on water table and soil moisture relationships, and on the influence of topography on site quality is suggested.

Additional References

Since the review of literature (Lake States Station Paper 32) was published in 1955, at least two other reports have been published on the subject of quaking aspen site requirements in Minnesota or the Lake States. There may also be others. The two referred to are the following:

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